Long Range, Coherent Synthetic Aperture Communications

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LONG TERM GOALS

The central effort of this research will be the development of robust and reliable algorithms for coherent acoustic communications at very long ranges in deep water.

OBJECTIVE

We will study coherent synthetic aperture communications (SAC) between a source and a receiver at speed and depth that exploits the relative motion between the two.

APPROACH

The application of time reversal processing to underwater acoustic communications has been studied extensively over the last several years [1-10] and [11] provides a concise overview on the time reversal receiver (Fig. 1). In theory, the time reversal approach combined with adaptive channel equalization provides nearly optimal performance [7]. In practice, it is robust and offers lower computational complexity.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **Long Range, Coherent Synthetic Aperture Communications**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Scripps Institution of oceanography,Marine Physical Laboratory,La Jolla,CA,92093**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The central effort of this research will be the development of robust and reliable algorithms for coherent acoustic communications at very long ranges in deep water.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

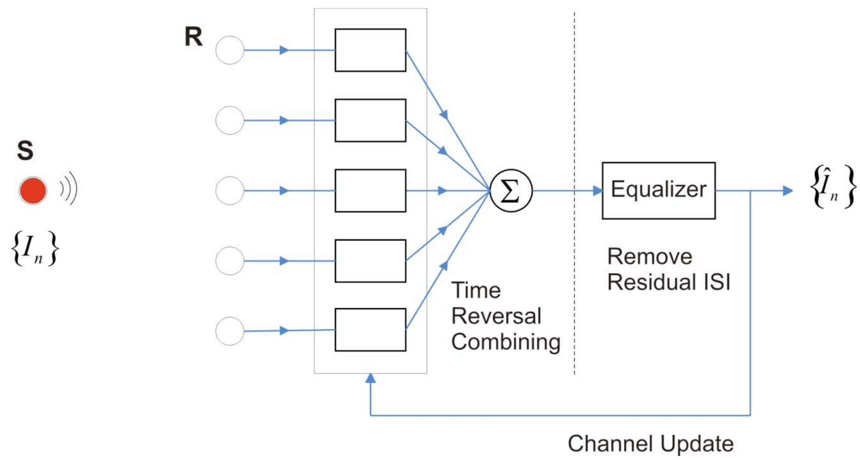

Figure 1. Schematic of optimal passive time reversal communication. It consists of three components: (1) time reversal multi-diversity combing, (2) single channel DFE equalizer, and (3) channel update using previously detected symbols to accommodate time-varying channel responses.

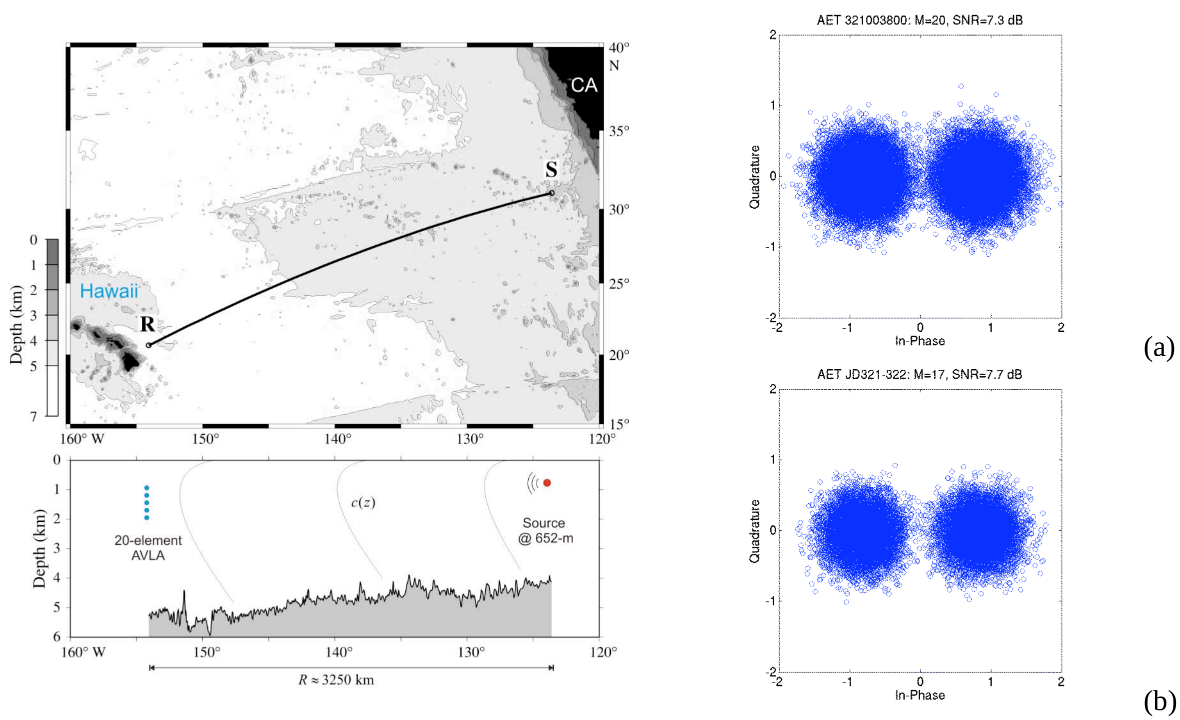

Figure 2. (Left) Acoustic path from the 75-Hz source S suspended from R/P FLIP off southern California to the vertical receiving array R moored east of Hawaii at approximately 3250 km range along with the bathymetry. (Right) Performance in terms of scatter plot: (a) vertical array diversity from M=20 elements and (b) temporal diversity combined from M=17 transmissions over a 2-day period (JD311-322) for a single element.

WORK COMPLETED

During November 1994, broadband acoustic signals were transmitted from a 75-Hz source to a 20-element, 700-m vertical array at approximately 3250 km range in the eastern North Pacific Ocean as part of the acoustic engineering test (AET) of the acoustic thermometry of ocean climate program [Worcester et al., *JASA* 105, 3185-3201 (1999)] (see Fig. 2). The AET was originally conducted as a tomography experiment in which the early arriving, weaker but visible and identifiable wavefronts were used for inversion of ocean properties (Fig. 3). Tomographers typically discard a majority of energy that is concentrated near the sound channel axis because the arrival structure cannot be related to a background ocean acoustic model. However, it is just this complex, high-energy late-arrival structure that can be utilized by acoustic time reversal communications. Note that the tomography signal can be treated as a binary-phase shift-keying (BPSK) communication signal with an information rate of 37.5 bits/s.

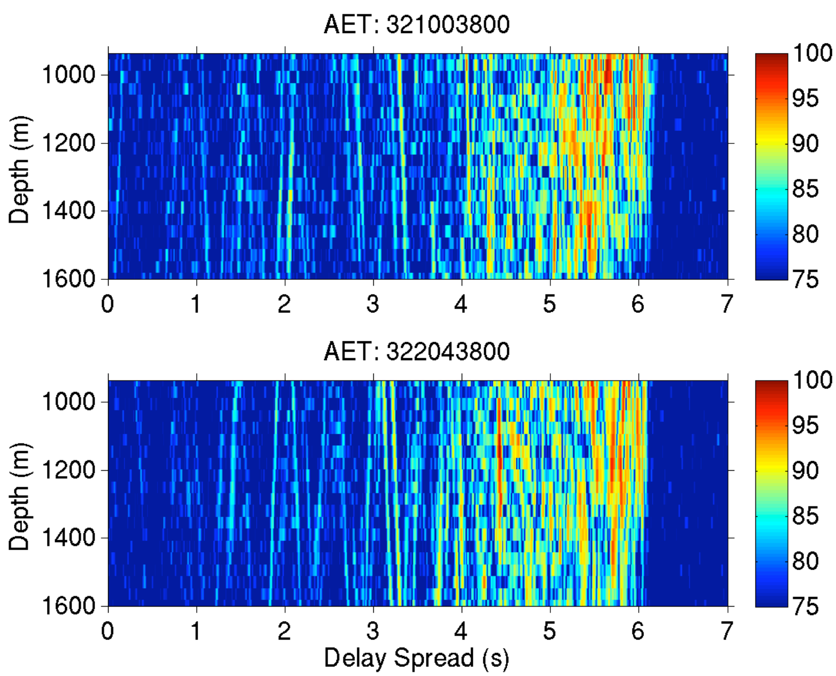

Figure 3. Acoustic intensity (dB) as a function of time delay spread and hydrophone depth for two ATOC AET receptions (one day apart). Early arriving wavefronts are visible but weak, while majority of the energy is concentrated on the later arrivals in the last 2-3 sec.

RESULTS

The performance of time reversal communications with continuous channel update applied to data (JD321003800) is displayed as a scatter plot in Fig. 2(a). The output SNR is 7.3 dB using all 20 elements of the vertical array (*M*=20) with a bit error rate (BER) of 49/34782.

The performance for a number of different transmissions over a 2-day period (JD321-JD322) is presented in Fig. 4 in terms of BER when *M*=20 (circles) and *M*=10 (triangles). The BERs are on the order 10^{-3} using *M*=20 and increase to approximately 10^{-2} when using only 10 elements (*M*=10).

Figure 4. Performance in terms of BER for different transmissions over a 2-day Block diagram for passive time reversal combining followed by a DFE.

To this point, time reversal communications at basin scale has been demonstrated exploiting the spatial diversity of a vertical array for individual 20-min long transmissions. It might also be possible to achieve similar diversity from temporal variations of the channel, provided that the channel responses are sufficiently uncorrelated with each other. To examine temporal diversity, we have selected a single element (Ch#1) and combine a total of 17 transmissions made over a 2-day period (JD321-322) with transmissions separated by 2 or 4 hr. In other words, this is single receive element communications with diversity being obtained from the multiple transmissions separated much longer than the coherence time. The comparable performance shown in Fig. 2(b) indicates that the ocean provided temporal diversity that is as effective as the spatial diversity provided by the array.

IMPACT/APPLICATIONS

Time reversal mirrors, either active or passive, exploit spatial diversity to achieve spatial and temporal focusing, a useful property for communications in an environment with significant multipath. In theory, the time reversal approach combined with adaptive channel equalization provides nearly optimal performance [7]. In practice, it is robust and offers lower computational complexity [8]. Normally, the time reversal approach assumes that the channel is time-invariant or slowly varying. Passive time reversal applies spatiotemporal matched filtering (Fig. 1) to combine multichannel data, either using measured channel responses from channel probes or initial channel estimates from training symbols. In dynamic ocean environment, however, the

channel can vary over substantially over time and the performance will deteriorate due to the mismatch between the actual and assumed channel responses. Thus, continuous channel updates prior to time reversal combining using previously detected symbols has been incorporated into the optimal time reversal approach to handle time-varying channels effectively [11,13].

Furthermore, the spatial diversity provided by the array has been extended to the temporal diversity integrating multiple transmissions using a single receive element. The implication is that the time reversal approach can be applicable to the synthetic aperture communications (SAC) that exploits the relative motion between a transmitter and a receiver [2,12]. The additional processing required for SAC will be: (1) estimation of the Doppler shift and (2) re-sampling of the received broadband signal. Then we can treat the moving source problem as a quasi-stationary problem where the channel responses vary in time due to the coupling of time and space in the presence of source motion.

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